UNLIMITED

AD 743328

TECHNICAL REPORT TR-72-6
January 1972

A SIMPLE WIDE BAND OMNI-DIRECTIONAL ANTENNA

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ABSTRACT

A compact vertically polarised antenna design based on a parabolic reflector is described. The antenna maintains omni-directional patterns (to within ± 1 dB) over a 33% band from 7.5 to 10.5 GHz. The measured gain at 8.5 GHz was 8.1 dB. A simple modification that converts the antenna to horizontal polarisation is also described.

ADMIRALTY SURFACE WEAPONS ESTABLISHMENT
PORTSMOUTH HANTS

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1. INTRODUCTION

1.1 A vertically polarised omni-directional antenna was required with a good performance over a 15-20% bandwidth at X band. A antenna gain of 8 dB was required at mid-band. To obtain a gain of this order with an omni-directional antenna means the elevation beam width has to be fairly narrow. If the gain of the antenna is to be used effectively over a wide band the elevation beam must not have any angular squint with frequency variation. This precludes the use of omni designs based on slotted wave-guide or other types of travelling wave antenna. The bandwidth stated above is easily met by use of log periodic structures but the gain requirement of 8 dB precludes use of most types of log periodic omni antenna design.

2. TYPES OF OMNI-DIRECTIONAL ANTENNA

2.1 Many designs of omni-directional antenna have been published, the choice of design is limited however if the following parameters are to be met.

1. Vertical polarisation.
2. Operational frequency bandwidth of 15-20%.
3. Midband gain 8 dB.
4. Omni radiation patterns to be maintained within ± 1 dB over the band.
5. Elevation pattern side lobes -10 dB maximum.
6. Elevation main beam normal to vertical axis with no angular beam squint with frequency changes.
7. Compact, lightweight design.

2.2 A comparison of five types of vertically polarised antennae is made in Figure 1. The "hour-glass" parabolic reflector design to be described, Figure 1d, is compared with four others. The sketches shown are to scale and antenna diameters for a given aperture size are given. The sizes resulting from an 18 cm aperture are also shown.

2.3 The biconical horn Figure 1a is seen to be a very bulky device if good elevation patterns and gain are required. To obtain well focussed patterns and full gain for a given aperture size, the phase error across the horn aperture should be small and to obtain this the horn length must be about three times the aperture size. The diameter of the antenna is therefore six times the aperture.

2.4 The diameter can be reduced to about 2.5 times the aperture if the lens corrected biconical horn is used, Figure 1b (Reference 1). A annular lens of solid or artificial dielectric, or a metal plate lens is used to correct the phase error at the aperture caused by the short horn length. Disadvantages of all designs based on the lens corrected bicone are that the resulting antennae are still large for high gains and also construction of the annular lenses in any of the dielectric stated is difficult. If a solid dielectric is used for the lens the resulting antenna is heavy and metal plate lenses of the n < 1 type would restrict the bandwidth of operation to about 10%.

2.5 Another antenna that has been used is shown in Figure 1c. This consists of a waveguide fed parabolic dish combined with a conical reflector to give an omni-directional pattern in azimuth. The minimum diameter with this arrangement is about twice the aperture, but the overall height is greater than the aperture height by the depth of the dish. The antenna is fairly large for high gains. An advantage of this antenna is that high r.f. powers can be transmitted by use of the waveguide feed.

2.6 Figure 1d shows the antenna to be described. It can be seen that the diameter is the same as the aperture size for this design so that compared with those in Figures 1a to 1c, it is more compact and lighter in weight.

2.7 The coaxial dipole antenna, Figure 1e, is described in Reference 2. This antenna is included so that a comparison can be made between omni antennae based on horns and parabolic reflectors and those based on standing or travelling wave arrays. The coaxial antenna has a very small diameter $\approx \frac{\lambda}{4}$ and is therefore a very compact device for low microwave frequencies, but it has several parameters that do not meet the requirements listed earlier. If a resonant or standing wave design of this antenna was used an elevation beam normal to the vertical axis of the antenna could be provided. However, end-fed resonant antennae are inherently narrow band devices especially when they are made long to give high gain. End-fed non-travelling wave antennae can be made to give bandwidths of 10% or more, but at the cost of a large elevation beam squint over the working band. The coaxial dipole omni is also difficult to make at frequencies above S-band because of the high tolerances required on the sleeve dipoles elements.

2.8 A further vertically polarised antenna is described in Reference 3. This has a wide bandwidth, 2-4 GHz with a gain of 7 dB. The elevation patterns however have high side lobes of -3 dB and the diameter is 7λ and height 4λ so that it is not a compact device.

3. THE EXPERIMENTAL ANTENNA

3.1 Two types of antenna based on the "hour-glass" shaped parabolic reflector are described in references 4 and 5. Reference 4 describes a scanning antenna, and reference 5 an omni antenna for UHF.

3.2 Development of a parabolic surface of revolution and the cross section of the antenna are shown in Figures 2a and 2b. The centre of revolution is taken as the directrix and by using a parabola with an f/d ratio of 0.25 the maximum diameter at the edge of the parabolic surface is the same as the height of the aperture.

3.3 The feed (Figure 2c) is a parallel plate waveguide region formed by two spaced metal discs, which divide the parabolic reflecting system into two symmetrical halves. The discs are energised at the centre by a coaxial line via a conical transition designed to improve the match over the working band. The discs are spaced towards their outer perimeter and beyond, by an annular ring of rigid plastic foam of high density. This is wedge shaped at the inner perimeter, to form a match to the parallel plate region, and its outer perimeter extends beyond the metal plate region by about one eighth of a wavelength (mid-band). It then terminates in an annular metal band (of about one half wavelength in height) which acts as a radiating energiser for the parabolic surface.

4. RADIATION PATTERNS

4.1 A antenna was constructed to the dimensions given in Figure 2 and the radiation patterns measured.

Figure 3a and 3b are the azimuthal omni-directional patterns and elevation patterns for four frequencies over a 1500 MHz band from 7.5 to 9.0 GHz. The omni patterns are seen to be within ± 0.75 dB for these frequencies. The elevation side lobes are not higher than -10 dB over this band. Patterns outside this band up to 10.5 GHz (33% bandwidth) are shown in Figures 4a and 4b. The omni patterns are within ± 1 dB over this increased bandwidth but the elevation side lobes have increased to -7 dB. The higher elevation side lobes indicate that if a wider bandwidth is required modifications to the simple annular feed would be needed if these side lobes are to be maintained at or below -10 dB.

5. VSWR AND GAIN

The VSWR was measured at the input to the coaxial line over a band from 8.25 to 11 GHz, Figure 4c. It is seen that the VSWR lies mainly between 1.5 and 2.5 over this band. The VSWR of the antenna and feed is probably better than is shown in Figure 4c, this is because for convenience a type "n" coaxial connector was used to terminate the coaxial line. Most connectors of this type do not have a VSWR better than 1.5 at X-band. The antenna gain measured at 8.5 GHz was 8.1 dB.

6. HORIZONTAL POLARISATION TEST

6.1 The antenna as described has vertically polarised omni-directional patterns. Re-design of the feed system for wide-band horizontally polarised omni patterns would be difficult. It was decided therefore to find out if the existing vertically polarised design could be converted to horizontal polarisation by means of a 90° polarisation twisting grid. A cylindrical form of grid would be needed to surround the antenna aperture.

6.2 Reference 6 describes a flat form of 45° polarising grid, and Figure 5 gives details of the grid used in the tests. The grid is required to give a change of polarisation of 90° and consists of eight layers of closely spaced copper wires mounted on 3 mm thick polystyrene foam sheets. The sheets are assembled into a multi-layer grid, Figure 5a. The angle of the wires of each layer is increased in the steps shown in the table alongside Figure 5b. Change of polarisation angle occurs progressively as the wave passes through the multi-layer grid. The first layer encountered by the wave must have the wires transverse or nearly so to the E field vector. The field vector progresses through the grid always remaining transverse to the wire layers, and leaves the grid transverse to the last wire layers.

6.3 Measurements of the VSWR of an 8 layer grid were made. A test section of grid was constructed similar to that shown in Figure 5a and was placed in front of a horn with a good match over X Band. The VSWR of the horn with grid is given in Figure 5b, this shows that the VSWR of the grid itself is very low. Figure 5c shows the cylindrical polarisation twisting grid in place over the antenna aperture.

7. HORIZONTALLY POLARISED PATTERNS

7.1 The radiation patterns of the antenna with polarising grid are shown in Figures 6a and 6b, for frequencies from 7.5 to 9.0 GHz. The omni-directional patterns are within ± 1 dB over the band, this is marginally worse than the antenna without the grid. The elevation patterns have side lobes of similar levels to those with no grid present for all frequencies except 7.5 and 9.0 GHz which have one side lobe increased by 2 dB. Patterns were taken at frequencies of 10.0 and 10.5 GHz (Figures 7a and 7b) for comparison with those in Figures 4a and 4b. The omni patterns are similar to those shown in Figure 4a and are within ± 0.75 dB. The elevation pattern side lobes are higher by about 2 dB to 5.5 dB at 10.0 GHz although the general characteristics of the patterns remain similar to those in Figure 4b. Figure 7c is a photograph of the antenna and polarising grid used in the tests.

8. CONCLUSIONS

8.1 An omni-directional antenna based on the "hour-glass" parabolic reflector has been tested at X Band. Good radiation patterns have been obtained in both azimuth and elevation planes over an 18% band from 7.5 to 9.0 GHz using a antenna with a simple annular feed. The omni patterns have power levels within ± 1 dB up to 10.5 GHz (33% band). The elevation patterns have side lobes below -10 dB from 7.5 to 9.0 GHz but these increase to -7 dB between 9.0 and 10.5 GHz. Improvements to the simple annular feed could probably be made to give lower side lobe levels above 9.0 GHz. The gain measured at 8.5 GHz was 8.1 dB.

Horizontally polarised omni patterns have been obtained by using a cylindrical polarising grid surrounding the aperture. The omni patterns with the grid present are within ± 1 dB from 7.5 to 10.5 GHz. The elevation side lobe levels are approximately 2 dB higher for frequencies above 8.5 GHz compared with those taken with no grid on the antenna. Use of a 90° polarisation twisting grid enables wide band horizontally polarised omni patterns to be obtained without modification to the vertically polarised antenna. The presence of the grid on the antenna caused a reduction in gain of less than 0.2 dB. The antenna is compact, lightweight and of simple mechanical design and it could easily be scaled to other frequency bands or re-designed for higher gains.

9. ACKNOWLEDGEMENTS

Mr R H Weston was responsible for the radiation patterns and other measurements carried out on the antenna.

10. REFERENCES

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3. "Mathematical and Experimental Studies of a Wide Band Vertically Polarised Antenna". P Foldes. IRE Transactions on Antennas and Propagation, AP-8, September 1960, pp 469-476.

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5. "Omni-directional Vertically Polarised Antenna". E O Willoughby and E Heider, IRE Transactions Antennas and Propagation, Vol AP-7 April 1959 pp 201-203.

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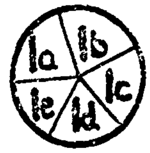
COMPARISON OF VERTICALLY POLARISED OMNI ANTENNAS



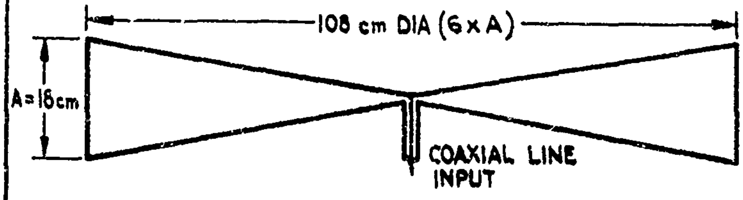


FIG. Ia BICONICAL HORN

ADVANTAGES
1. VERY WIDE BAND.
2. SIMPLE DESIGN.

DISADVANTAGES
1. VERY LARGE SIZE FOR MEDIUM TO HIGH GAINS.
2. TO OBTAIN FULL GAIN AND GOOD ELEVATION PATTERNS MINIMUM DIAMETER ≏ 6 x RADIATING APERTURE.

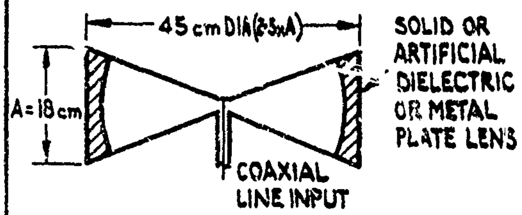


FIG. Ib LENS CORRECTED BICONICAL HORN

ADVANTAGES
1. WIDE BAND IN CASE OF DIELECTRIC LENS WITH MATCHED SURFACES.
2. SMALLER THAN SIMPLE BICONE.

DISADVANTAGES
1. LARGE SIZE FOR HIGH GAIN DESIGN.
2. SOLID DIELECTRIC LENS DESIGN IS HEAVY.
3. ANNULAR LENSES DIFFICULT TO CONSTRUCT.
4. BAND RESTRICTED TO 10% WITH METAL PLATE LENS.

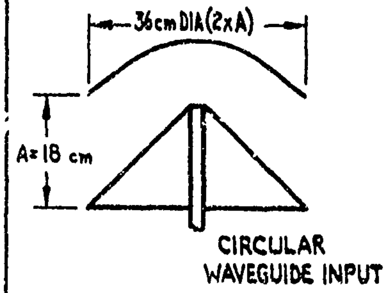


FIG. Ic PARABOLIC DISH WITH CONICAL REFLECTOR

ADVANTAGES
1. LIGHT WEIGHT.
2. WAVEGUIDE FEED ALLOWS HIGH POWERS TO BE TRANSMITTED.

DISADVANTAGES
1. LARGE SIZE FOR HIGH GAIN DESIGN.

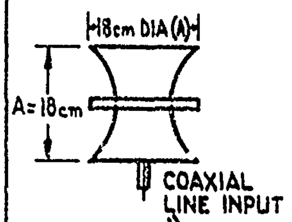


FIG. Id "HOUR GLASS" PARABOLIC REFLECTOR

ADVANTAGES
1. LIGHT WEIGHT.
2. COMPACT SIZE FOR HIGH GAIN DESIGN.
3. WIDE BAND PERFORMANCE.

DISADVANTAGES
1. CENTRALLY MOUNTED FEED GIVES HIGH ELEVATION SIDE LOBES FOR SMALL APERTURE DESIGNS DUE TO APERTURE BLOCKING.

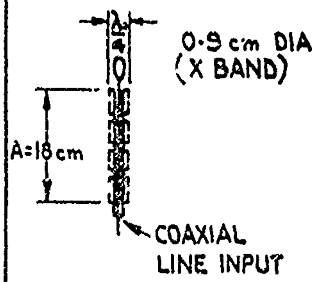


FIG. Ie COAXIAL ANTENNA USING SLEEVE DIPOLES

ADVANTAGES
1. LIGHT WEIGHT.
2. VERY SMALL DIAMETER

DISADVANTAGES
1. IMPRACTICAL FOR FREQUENCIES ABOVE S BAND BECAUSE OF DIPOLE TOLERANCES.
2. ELEVATION BEAM SQUINTS WITH FREQUENCY CHANGE.
3. BANDWIDTH ≏ 10% MAX.

THE OMNI - DIRECTIONAL ANTENNA

2a 2b 2c

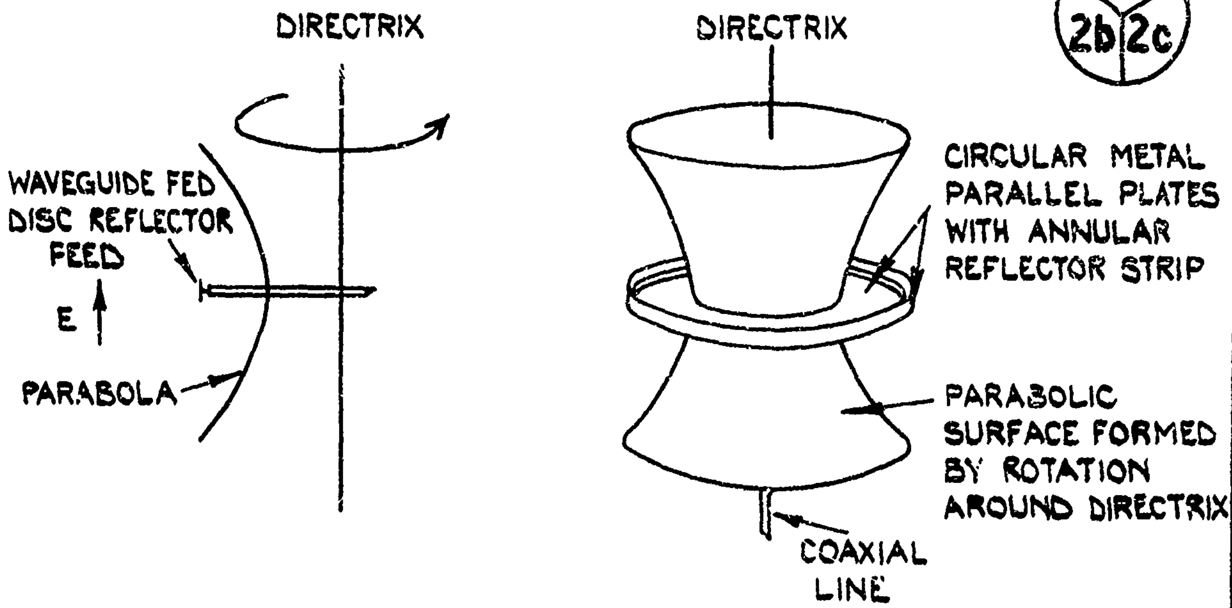


FIG. 2a DEVELOPMENT OF THE OMNI ANTENNA

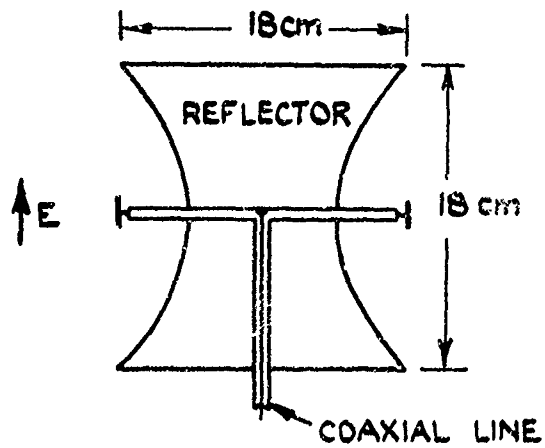


FIG. 2b SECTION THROUGH EXPERIMENTAL ANTENNA

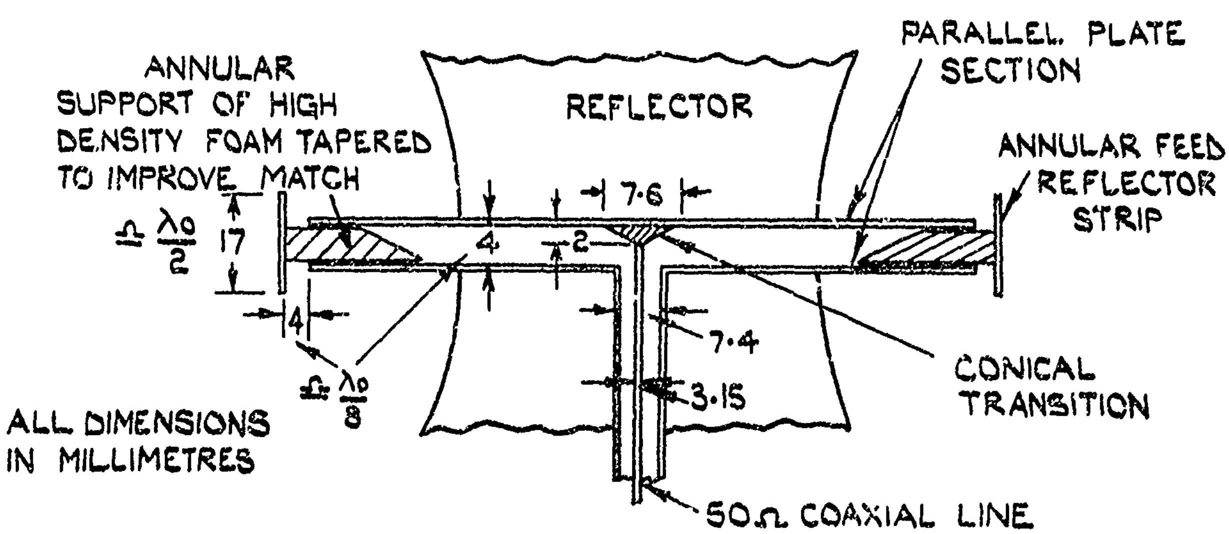


FIG. 2c SECTION THROUGH ANNULAR FEED

RADIATION PATTERNS OF EXPERIMENTAL ANTENNA

3a / 3b

FIG.3a AZIMUTH PATTERNS

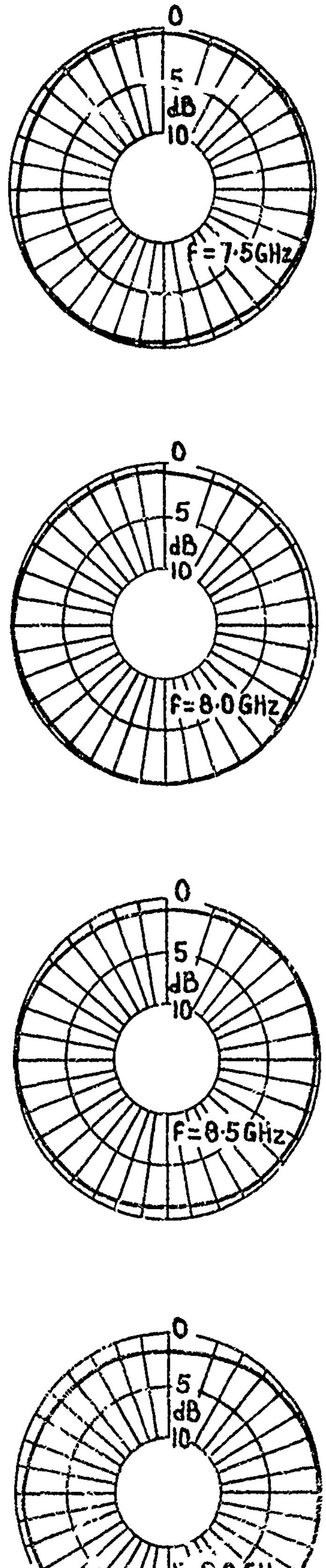
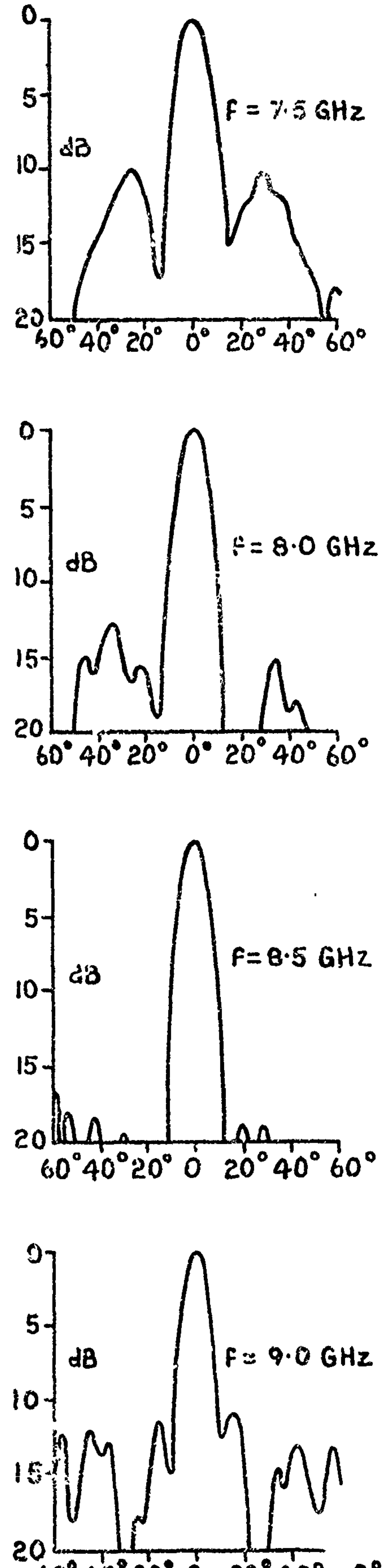


FIG.3b ELEVATION PATTERNS



4a 4b 4c

FIG. 4a. AZIMUTH PATTERNS
(VERTICALLY POLARISED)

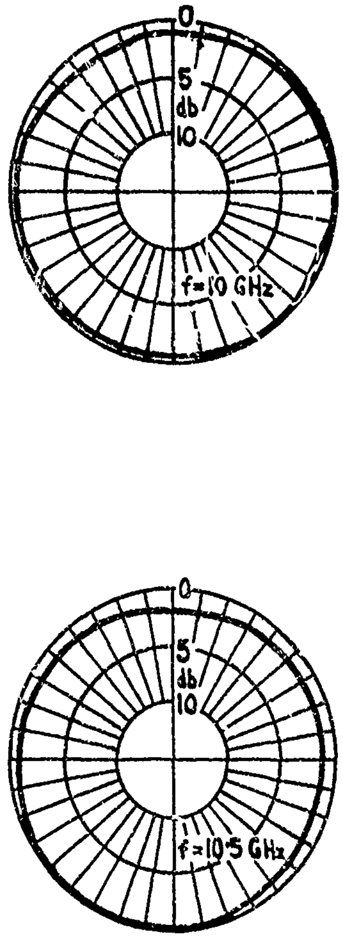
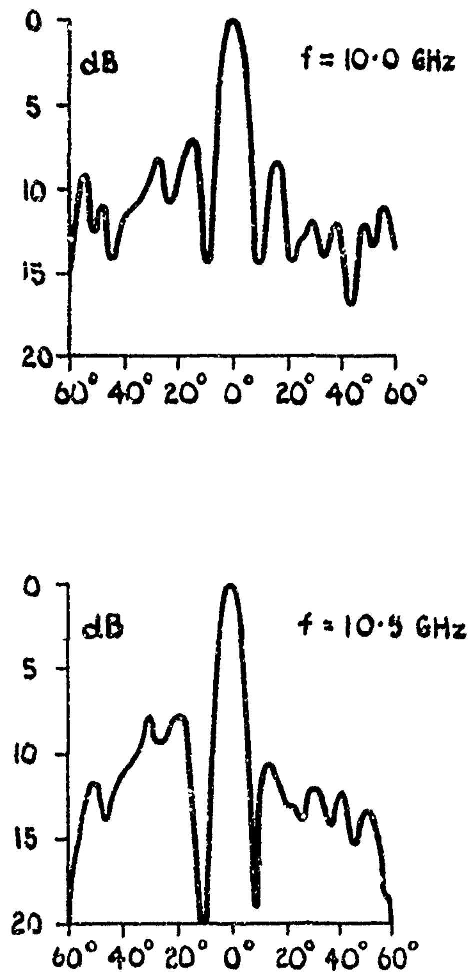


FIG. 4b. ELEVATION PATTERNS



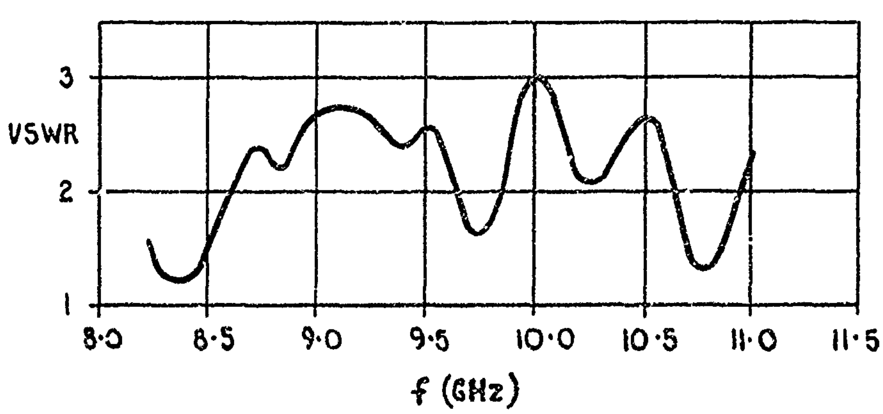


FIG. 4c. VSWR OF ANTENNA

90° POLARISATION TWISTING GRID

5a 5b 5c

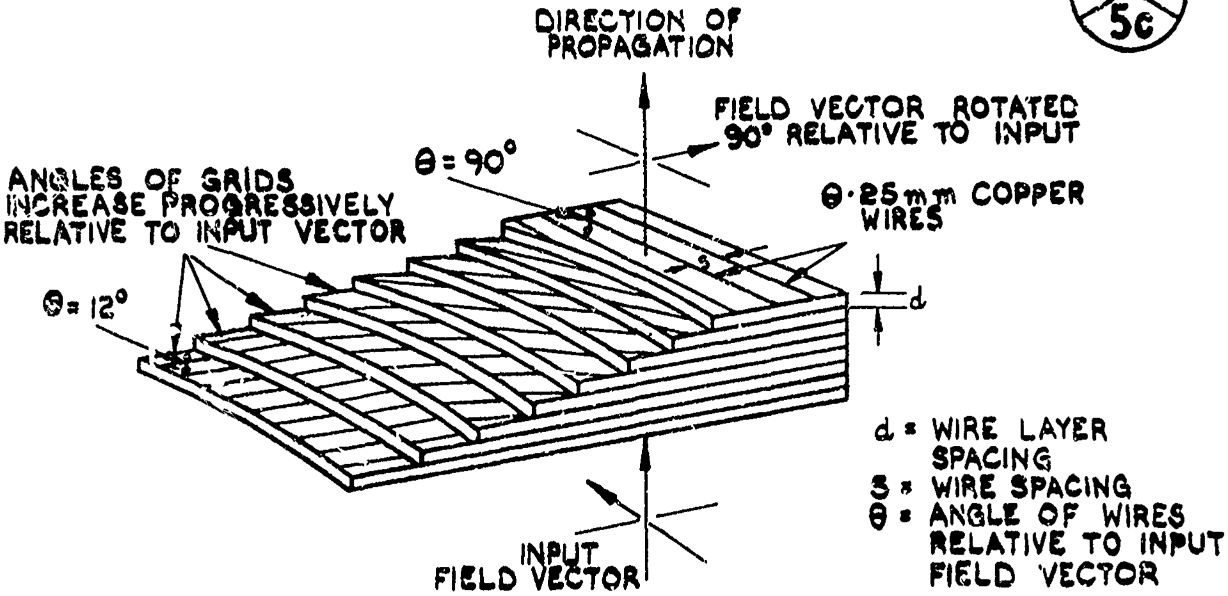
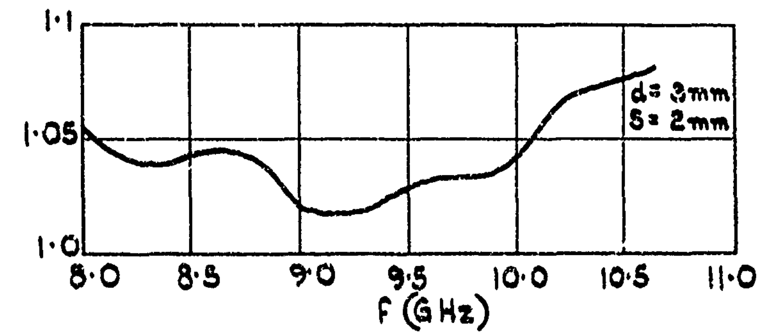


FIG. 5a CONSTRUCTION OF AN EIGHT LAYER POLARISATION TWISTING GRID



LAYER	θ°
1	12°
2	23°
3	34°
4	45°
5	56°
6	67°
7	78°
8	90°

90° GRID DETAILS

FIG. 5b. VSWR OF AN EIGHT LAYER 90° POLARISATION TWISTING GRID

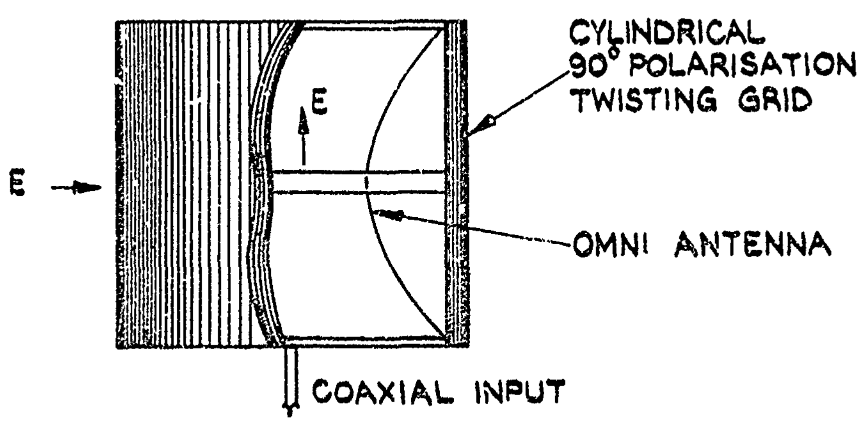


FIG. 5c. VERTICALLY POLARISED OMNI ANTENNA CONVERTED FOR HORIZONTAL POLARISATION

RADIATION PATTERNS OF ANTENNA WITH 90° POLARISATION TWISTING GRID.

6a
6b

FIG. 6a. AZIMUTH PATTERNS (HORIZONTAL POLARISATION)

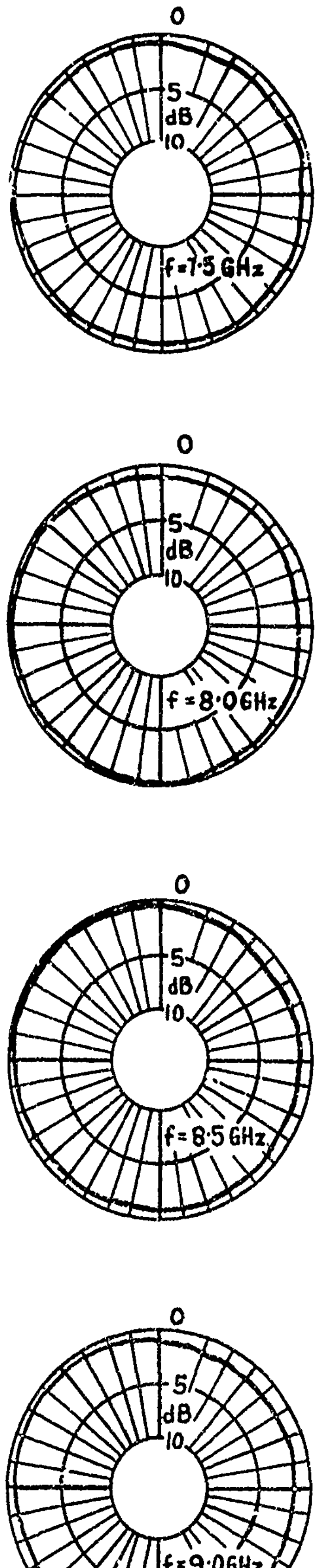


FIG. 6b. ELEVATION

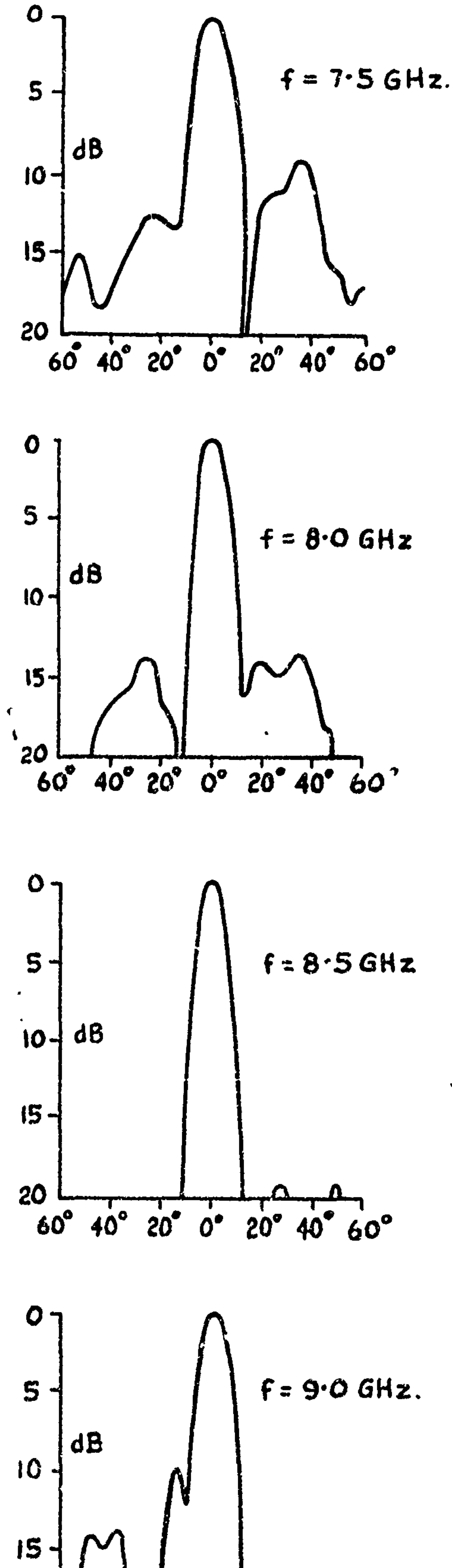
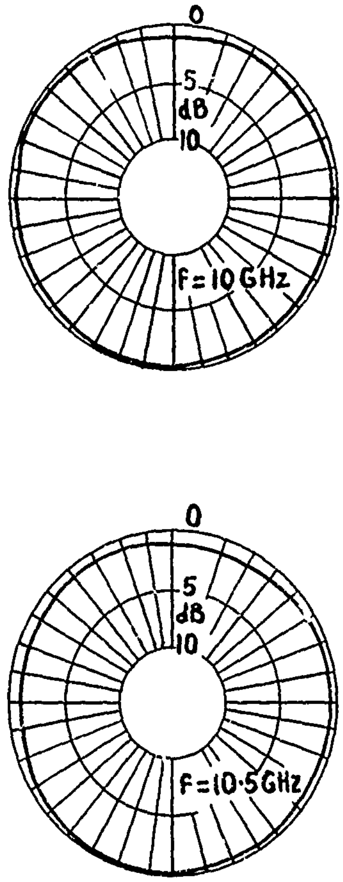
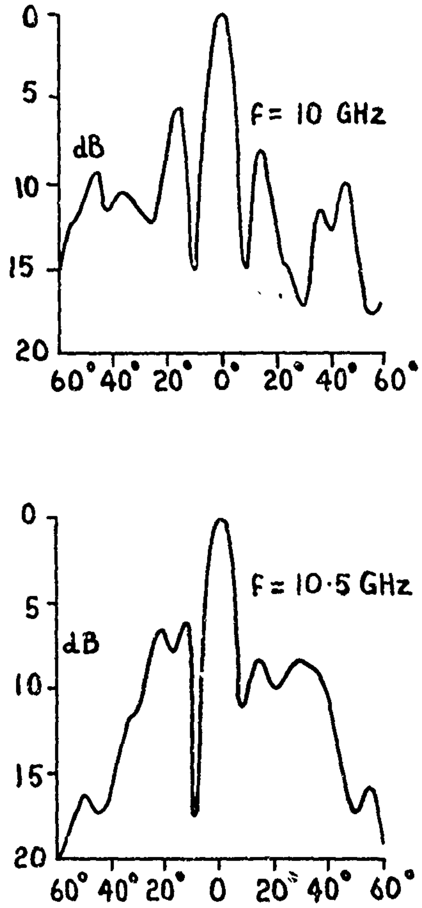


FIG. 7a AZIMUTH PATTERNS HORIZONTALLY POLARISED

FIG. 7b ELEVATION PATTERNS

7a 7b 7c





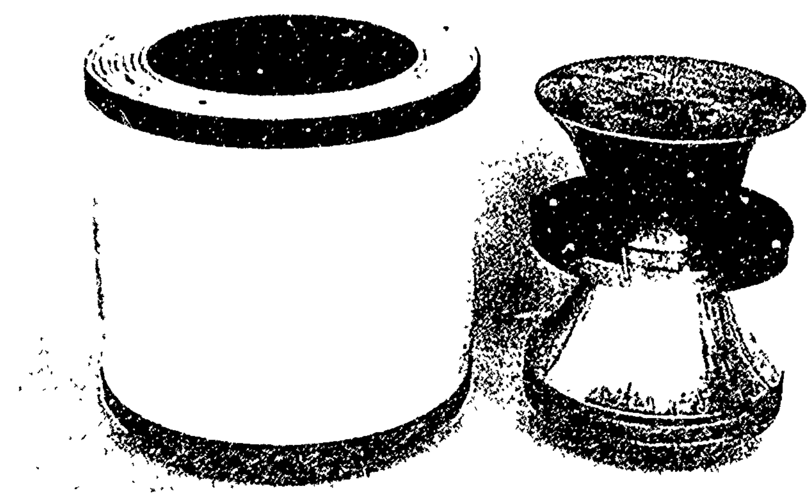


FIG. 7c ANTENNA AND POLARISING GRID